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Effect of the Fastskin[registered trademark symbol] swimsuit on physiological and biomechanical responses of freestyle swimming

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Effect of the Fastskin^{TM} swimsuit on physiological and biomechanical responses of freestyle swimming

by

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Signatures have been redacted for privacy

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CHAPTER I

INTRODUCTION

Over the past 15 years research has tried to enhance swimming performance by studying ways of reducing the drag forces acting on a swimmer. For example removal of body hair and utilization of wetsuits and a torso body suit have been related to significant improvements in swimming performance. The influence of changing buoyant force and drag on swimmers and its affect on the associated metabolic cost of swimming has been examined. Capelli et al. (2) and Zamparo et al. (28) found that changes in buoyant and drag characteristics were responsible for approximately 70% of the subsequent changes in blood lactate concentration and oxygen uptake. Reducing resistive forces encountered by competitive swimmers while swimming is known to reduce the physiologic cost during submaximal swimming and prior studies have used either wet suits or removal of human body hair to demonstrate this effect.

Shaving body hair is one way for a swimmer to improve performance. Sharp and Costill (20) concluded that shaving body hair reduces active drag and causes a significant decrease in post-swim blood lactate concentration and oxygen uptake of swimming 366-m breaststroke. The authors also found a significantly increased distance per stroke and reduced wall push-off velocity decay which provided support for the decreased active drag, thereby leading to improved performance.

Another way in which swimming performance has been enhanced has been the use of wet suits in triathlon swimming events. The use of neoprene wet suits is illegal in swimming competitions, but is allowed in the swimming leg of the triathlon. In the first study on wet suits, Parsons and Day (18) found that the use of wet suits increased swimmer speed by about 7%. One speculation for the results was an increase in the buoyant force experienced by the swimmer. The increase in buoyancy decreases drag by reducing the frontal area of the body exposed to the water flow. The results of Toussaint et al. (25) support altered buoyancy as the mechanism for the decreased drag as they found that active drag was reduced by 14% while wearing wet suits. Trappe at al. (26) examined the physiological effects of wearing a wet suit and showed that oxygen uptake was significantly lower during the wet suit trials compared to traditional brief-style racing suits. Starling et al. (22) studied a torso body suit made of similar material of the body suit being used in this study and found a significantly reduced blood lactate concentration, increased distance per stroke, and greater total glide distance during their wet suit trial. Together, these studies suggest swimmers can improve performance by increasing buoyancy, thus causing a decrease in drag, which ultimately leads to lowering the metabolic requirements of swimming at any given velocity.

Recently, new competitive body suits were introduced that are claimed by some to enhance performance by reducing drag. This new body suit fits extremely snug to the body and is designed to mimic the skin of a shark. As a result of the unique design the manufacturer claims the passive drag experienced by the athlete is 7.5% less than any other suit. This reduced water resistance may therefore improve swimming efficiency and performance by reducing the energy required in attaining competitive speeds during races. Despite these claims, there is no published literature that suggests these suits provide the benefits as claimed or whether the swimmers' energy cost is affected.

Statement of Problem

The purpose of this study was to assess the effect of wearing a Fastskin^{TM} (Speedo Int. Ltd., Los Angeles, CA) swimsuit on physiological variables, including post-swim oxygen uptake and blood lactic acid concentration, and biomechanical variables, including passive drag, buoyancy and stroke mechanics, as related to performance. It was hypothesized that the Fastskin^{TM} swimsuit would not increase buoyancy or decrease passive drag. It was also hypothesized that the body suits would have no effect on the physiological measures, thus causing no improvement in submaximal swim performance.

Review of Literature

Metabolic Cost of Swimming

The production of lactic acid and its accumulation during swimming is generally thought to be a reflection of the metabolic cost of performance (1). Another popular method to examine metabolic cost is to evaluate oxygen uptake. Economy, the relationship between oxygen consumption and velocity, is probably the most common way to assess this metabolic requirement of swimming (5,7,10,11,12,23,27). Typically the lactic acid concentration is also examined by considering its relationship to velocity. For a given performance, a particular swimmer is going to have a fairly constant oxygen uptake and blood lactate concentration at that velocity. After training over the course of a season, aerobic conditioning will increase and the body will be able to exercise at a given speed at a reduced metabolic cost. The same adaptation holds true for blood lactate. The body will become more effective at reducing accumulated blood lactate, thus causing the lactate velocity curve to shift downward allowing the athlete to perform at the same speed as before at a lower energy expenditure.

Shaving body hair, which is a common practice at important competitions, is one way to decrease the metabolic cost of swimming at a specific velocity. Sharp and Costill (20) studied the effects of shaving on various physiological variables of 9 male swimmers who performed a 400-yard swim. They found that oxygen uptake was significantly decreased in their experimental subjects from pre (3.60 ± 0.15 l/min) to post-test (3.27 ± 0.14 l/min). The authors also found a significant decrease in blood lactate concentration from pre to post-test in the experimental group (pre: 8.41 ± 0.79 to post: 6.73 ± 0.74 mmol/l). In another shaving study performed on six subjects who swam four 200-yard swims similar results were found with regard to blood lactate (21). The first three swims of the shaved trial differed significantly from the unshaved trial, 3.72 ± 0.51 to 4.16 ± 0.47; 4.55 ± 0.50 to 5.68 ± 0.55; and 7.06 ± 0.52 to 7.36 ± 0.56 mmol/l respectively.

Another method of decreasing metabolic demands at a given velocity is to utilize a wet suit. Starling et al. (22) studied 8 male swimmers wearing a torso suit and a standard racing suit while swimming 400-yard freestyle swims to determine if swimsuit design had any effect on energy demands. Results indicated that both oxygen uptake (3.92 ± 0.18 to 3.76 ± 0.16 l/min) and blood lactate concentration (9.66 ± 0.66 to 8.08 ± 0.53mmol/l) were significantly reduced by wearing the torso suit. In summary, the authors speculated the underlying factors effecting these important metabolic changes that enhance performance include a reduction in drag, an increase in buoyancy and an increased distance per stroke.

Drag

A majority of the energy expended in swimming is used to overcome drag (14). Since most of the metabolic energy is used to not only overcome the resistance of the water, but to propel the body forward it should be obvious that drag is the most important factor affecting swimming success. To further examine drag in swimming, the drag force must be split into its major components - form, surface, and wave drag (4,15,19,24,25).

Form drag is the eddy resistance and frontal resistance produced from the movement of an object through the water (19). It is the shape of the object that is important. In swimming, form drag directly relates to streamlining off of a turn among other things. A swimmer wants to reduce form drag by decreasing the cross-sectional area exposed to the water. This would be achieved by becoming as horizontal in the water as possible and tightening the arms and legs together as snugly as possible during the streamline (15). Toussaint et al. (24) indicate a pressure drag may have an effect on this form drag. The researchers state that increased buoyancy will be achieved if the suit has a low specific gravity and this will lead to a reduced frontal area exposed in the direction of travel.

Surface drag is another component of drag and relates to the interaction between the surface of the object and the surface of the water and probably has a small effect of swim performance (19,22). A smooth object is going to produce less friction and this should cause a decrease in the surface drag. Several studies which examined the effect of shaving and wet suits suggest that this component of drag is important, cannot be overlooked and is responsible for its share of the enhanced performance.

Wave drag refers to creating waves and the resistance caused from the interaction between the swimmer and the top of the water (15). The size and dimensions of the swimmer are what determines wave drag.

Research suggests that a decrease in any of the components of drag may reduce the metabolic responses to submaximal swimming. A reduction in drag would reduce the physiologic demands of swimming at a particular velocity by allowing the swimmer to increase distance per stroke while using less energy to obtain that velocity (20,21). In their shave down study, Sharp and Costill (20) came to this conclusion because the velocity decay data from the prone glide push-off test indicated that swimmers with an absence of body hair were able to maintain the high velocity for a longer period of time than the same group of swimmers with body hair.

The use of wet suits may be another way to obtain the enhanced performance from the benefits of a decreased body drag. Toussaint et al. (25) found that a reduction in drag force of 12-16% while wearing a wet suit during swimming at velocities of 1.10, 1.25, and 1.50 m/sec. Starling et al. (22), who studied physiological changes with use of the torso suit, hypothesized that the torso suit altered the frictional drag in such a way as to decrease the active drag causing a reduced metabolic cost to the swim. The results of the wet suit and torso suit study appear to concur with the finding of the shave down study that suggest such a small change in frictional resistance may cause a significant decrease in drag leading to improved swim performance.

Buoyancy

Buoyancy is a vertical force equal to the weight of water displaced by an object. The center of buoyancy is the point of application of this buoyancy force and is compared to the center of gravity of the swimmer. If the center of buoyancy and the center of mass of the swimmer are at the same location then the swimmer will float in a horizontal position. However, the center of mass is usually more caudal than the center of buoyancy causing the legs to drop in the water. When the legs sink the drag force the swimmer experiences increases, which subsequently causes the performance to decrease (16,17). This buoyancy factor is very important as it has implications related to swim performance due to potential reductions in drag forces, energy cost and time (2,3,5,6,25,28).

Research has indicated that the hydrostatic lift component of the buoyant force accounts for 8-10% of the variance in 400 yd. swim performance (3,5). McLean and Hinrichs (16) also found that the buoyant force accounted for 10% of the variance in 25-yd. performance when they controlled for gender. The above results suggest that buoyant force and buoyant characteristics influence the size of the drag force the swimmer must overcome. Research indicated this increase in buoyant force was responsible for about 70% of the metabolic changes associated with swimming (2,28). In summary, it would be advantageous to increase buoyancy to enhance performance. The utilization of wet suits may be the answer to artificially increasing buoyancy and improving performance. Toussaint et al. (25) state that wet suit fabric (primarily neoprene) has a low specific gravity, which is related to the coefficient of drag in the drag force equation. This decrease in the coefficient of drag will increase the buoyant force, causing a reduction in the frontal area component of the surface drag, ultimately leading to enhanced performance (25).

Thesis Organization

The first part of the thesis is the first chapter which contains a general introduction and a review of literature. The second chapter of the thesis comprises a manuscript to be submitted to *Medicine and Science in Sports and Exercise*. The third and final chapter is a general conclusion. The last part of the thesis is made up of an appendix section that contains the informed consent form. References used throughout the general introduction and general conclusion are listed in the final reference section.

CHAPTER II

EFFECT OF THE FASTSKIN™ SWIMSUIT ON PHYSIOLOGICAL AND BIOMECHANICAL RESPONSES TO FREESTYLE SWIMMING

A paper to be submitted to Medicine & Science in Sports & Exercise

B. Scott Roberts, Scott P. McLean & Rick L. Sharp

ABSTRACT

The introduction of new body swimsuits to competitive swimming has caused a great deal of controversy. These suits are snug to the body and supposedly reduce drag, therefore improving swim efficiency and performance by reducing the energy required to attain speed during races. The purpose of this study was to examine one particular body swimsuit, the Fastskin™ (Speedo Int. Ltd., Los Angeles, CA), on biomechanical variables and the physiological cost of swimming. Subjects same three 183-m freestyle trials at "moderate, moderately hard and hard" paces while wearing the body suit and a traditional brief-style suit. Post-swim blood lactate concentrations, oxygen uptake, and ratings of perceived exertion were gathered. Average stroke length and rate, and breakout distance were determined for each swimming trial. Passive drag and buoyant force were determined wearing both suits. Post-swim blood lactate concentration and stroke length were significantly higher when wearing the body suit. Comparison of physiological variables at standardized speeds of 1.4 and 1.6 m/s revealed no significant difference between the two suit conditions. Passive drag was not significantly different between the body suit and brief-style suit, but the brief-style suit was slightly more buoyant than the body suit. Swimmers swam at a higher absolute mean velocity while wearing the body suit, but this was accompanied by a significant increase in metabolic

cost. If the suits had provided the benefit of decreased drag as claimed by the manufacturer, the swimmer would have swum at a lower metabolic cost for a given speed when wearing the body suit as compared to the brief-style suit. Therefore, it is concluded that combined effect of increased body surface area covered and design of the suit material had no measurable effect on submaximal physiological responses to swimming.

Key Words: BODY SUITS, OXYGEN UPTAKE, BLOOD LACTATE, DRAG, BUOYANCY

Introduction

During the 2000 Summer Olympic games 12 swimming world records were broken. Although it was not uncommon for world records to be broken at an Olympics, much attention was focused on the use of a new style of racing swimsuit known as the body suit. Several manufacturers have developed such suits with each making similar claims about the effect that the suit would have on the swimmer.

One particular suit, the Fastskin™, introduced by Speedo International Ltd. (Los Angeles, CA) has several design features based on the idea of reducing the drag experienced by the swimmer during a race. The suit material was designed to mimic the skin of a shark. It uses built-in V-shaped ridges to decrease drag and turbulence. The suits also are snug fitting to the body and cover an increased body surface area compared to the traditional brief-style suit, both of which are thought to affect drag. Testing conducted by Speedo indicated that the Fastskin™ swimsuit reduced surface drag by 3% over the suit's predecessor and was 7.5% faster than any other suit they tested. This reduced water resistance may therefore improve swimming efficiency and performance by reducing the energy required to attain speed during races. Furthermore, it is popularly believed that these suits will improve the buoyancy characteristics of the swimmer. Even though the suits are neutrally buoyant, the use of this material on the legs may have a beneficial affect by reducing the overall density of the legs and thus increasing the buoyant force acting on the swimmer (5). Despite these claims, there are no published data to support the manufacturer claims or the anecdotal claims of swimmers that the use of these suits will improve performance.

Two possible mechanisms by which competitive swim performance can be improved are increased buoyancy and reduced drag. By artificially manipulating buoyancy characteristics of swimmers, Capelli et al. (2) and Zamparo et al. (13) found that the changes in buoyancy accounted for 70% of the change in metabolic cost of swimming. Wearing neoprene suits or a torso body suit during swimming improves performance (3,7,11,12), decreases drag by increasing buoyancy (7,11,12) and reduces the metabolic cost (3,10,12) of swimming at a given speed. Likewise, shaving exposed body hair has been shown to reduce the metabolic cost of swimming either freestyle (9) or breaststroke (8).

If the Fastskin™ swimsuit has a favorable effect on drag or buoyancy, then it is reasonable to expect an increase in swimming velocity at a reduced or equivalent metabolic cost similar to that of shaving body hair and wearing a wet suit or torso body suit. However, to date there have been no published reports of studies to assess buoyancy, drag and metabolic cost of swimming while wearing these suits. It is the purpose of this study to assess the effect of wearing a Fastskin™ swimsuit on swimming performance by evaluating the changes in physiological and mechanical responses associated with the use of this suit. It was hypothesized that use of the Fastskin™

swimsuit would not affect swimming performance. Furthermore, it was hypothesized that use of the Fastskin™ swimsuit would not lower oxygen uptake or blood lactic acid concentration, increase buoyancy, decrease passive drag, or alter stroke characteristics.

Methods

Subjects

Ten male swimmers (age = 20.2 ± 1.5 yrs, height = 183.8 ± 5.5 cm, and weight = 79.6 ± 7.4 kg) currently training and competing at the collegiate level (NCAA Division I) provided informed consent prior to participation in the study. Competitive swimmers were selected as subjects to control for differences in performance attributable to technique and skill level. The Institutional Review Board for Iowa State University approved this study.

Protocol

A randomized repeated measures design was used to compare passive drag, buoyancy, and submaximal physiological responses to swimming, when wearing a traditional competition brief-style suit to wearing a Fastskin™, hereafter referred to as the body suit. For each measurement the subjects completed testing once wearing a body suit and again wearing the brief-style suit. The style of the body suit chosen for this study was the sleeveless, full torso, ankle-length suit. The competitive briefs were made of LYCRA®.

Subjects reported for testing on two days, separated by one week. Each subject performed three 183-m freestyle swims. To balance the presentation of suit conditions between data collection sessions five of the ten subjects were randomly chosen to use the body suit on the first day of collection while the other five used the brief-style suit.

These conditions were switched on the second day of testing. After checking in, the subjects' height and weight were measured. If the swimmer was using the brief-style suit, buoyancy measurements were made prior to warm-up. If the swimmer was using the body suit, he warmed-up in a brief-style suit, and then put on the body suit so the buoyancy measurement was made in a dry body suit. Warm-up was self-determined by each swimmer and was repeated prior to the second data collection session. After completion of the static buoyancy measurement and warm-up the swimmer received instructions for the swim test. The subject was asked to perform the first swim at a "moderate" pace, the second swim at a "moderately hard" pace, and the third swim at a "hard" pace. In addition, it was suggested that the subject decrease his time by roughly 5 seconds across consecutive swims. The swims were timed from when the feet broke contact with the starting wall and finished when the hand touched the finishing wall. Immediately upon finishing the swim, post-exercise oxygen uptake was collected for 45 sec. One minute into the recovery period a blood sample was collected. Following that, the subject was presented with the Borg Scale and selected a representative value for that particular swim (1). The three swims were separated by 2 minutes of passive recovery. Water temperature (28° C) and environmental conditions (24° C, 75% humidity) were similar for both test days. The subjects performed the same protocol one week later and were asked to duplicate the times recorded for the swims from the previous week.

During a third testing session, subjects were tested in groups of five for the passive drag measurement. It was easier for the subjects to put the body suit on when dry. Therefore, nine of the 10 subjects were tested wearing the body suit first to facilitate changing suits. The remaining subject wore the regular competition suit first in order to share a body suit with one of the other swimmers. Subjects completed three trials each at the slow and fast speeds. Subjects were removed from the drag measuring apparatus between trials such that each subject within a group of five completed one trial before a second trial of any subject was collected. Once all subjects within a group had completed three trials at a given speed, flow speed was adjusted and the protocol was repeated. After all trials were completed for a given condition, subjects changed suits and repeated the protocol using the other suit.

Physiological Measurements

Post-swim oxygen uptake collection began immediately after completion of the 183-m swim. A mouthpiece was inserted and the subject pinched his nose shut as he breathed through the mouthpiece for 45 sec (Physio-Dyne Max-1 Metabolic System, Quogue, NY). Expired air was collected in a 3-L mixing chamber and VO_2, VCO_2, and RER were measured on a breath-by-breath basis and recorded every 5 sec. Each subject's post-swim oxygen uptake was corrected to reflect peak exercise oxygen uptake using a regression equation fitted to each 5 sec. integrated VO_2 and extrapolated back to time zero (Figure 1). To compare the post-swim oxygen uptake responses between testing sessions, a line of best fit across the three speeds achieved during each testing session was determined. Standardized post-swim oxygen uptake values were then used in data analysis. This particular example was a "moderately hard" swim in the brief-style suit. computed using each individual regression equation for the speeds of 1.4 and 1.6 m/s (Figure 2). The correlation coefficients for these trials ranged from 0.83 to 1.00.

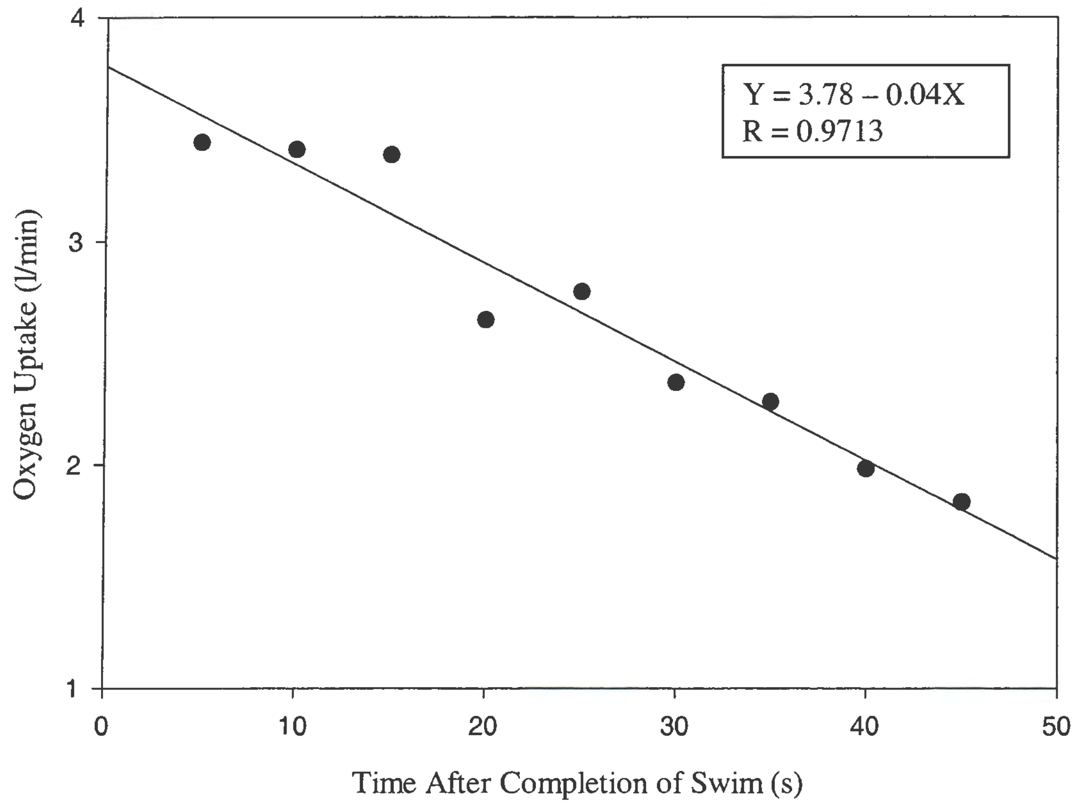

Figure 1. Example of backward extrapolation of post-swim oxygen uptake to determine the time zero value, or peak oxygen uptake value for that particular swim, which was

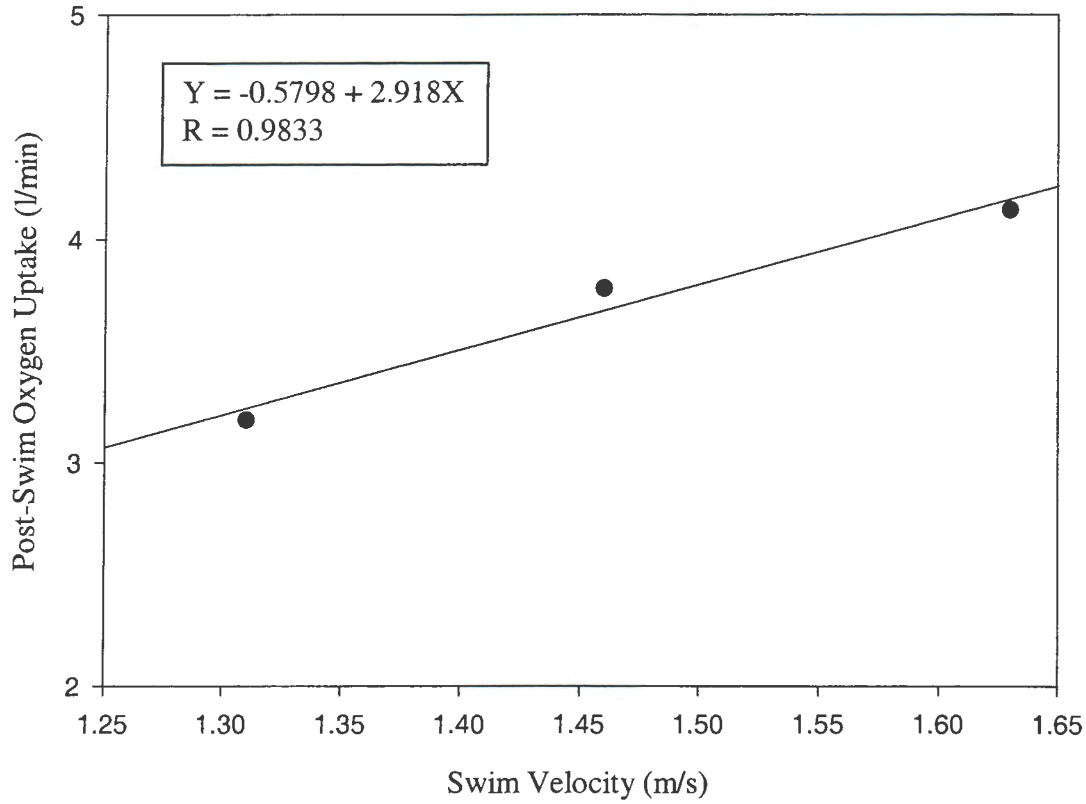

Figure 2. Example of linear regression to demonstrate extrapolation of values corresponding to 1.4 and 1.6 m/s. This particular example came from the brief-style swimsuit for the “moderate, moderately hard, and hard” swims.

Blood samples collected one-minute post-swim were analyzed for blood lactate concentrations (10). A 20-microliter fingertip blood sample was collected and immediately deproteinized in 2 N perchloric acid. The blood samples were then centrifuged and stored at 4 degrees Celsius until later analysis of lactic acid concentration using an enzymatic spectrophotometric assay (4). The blood lactate values were then transformed to common logarithm (9) and standardized to velocities of 1.4 and 1.6 m/s using linear regression. The correlation coefficients for these trials ranged from 0.85 to 1.00.

Rating of perceived exertion was measured using the Borg Scale to indicate their perception of effort for that particular trial (1). The scale was presented to each subject approximately a minute and a half into recovery. The RPE values were also standardized at 1.4 and 1.6 m/s using linear regression that was fitted across the three swim velocities. The correlation coefficients for these trails ranged from 0.93 to 1.00.

Stroke Characteristic Measurement

Each swim trial was video taped. Breakout distance, stroke rate, and stroke length were measured and averaged for all 8 lengths of the pool. Breakout distance was defined as the distance from the wall to the point the head broke the surface of the water. The total number of complete stroke cycles were counted from the first visible hand entry during a given length of the swim to the instant when the head of the swimmer reached a point 4.6 m from the wall. Stroking distance was then computed by determining the location of the swimmer's head where the stroke count began and the point where the stroke count ceased. Stroke length (SL) was then calculated as

$$SL = \frac{Stroking\ Distance}{\#\ of\ Strokes} \tag{1}$$

Stroking time was measured using a manual stopwatch to measure the time needed to complete the stroking distance. Stroke rate was then calculated as

$$SR = \frac{\#\ of\ Strokes}{Stroking\ Time} \tag{2}$$

Average stroke length, stroke rate and breakout distance for all 8 measurements during each swim was used in statistical analysis to compare responses between suits.

Passive Drag Measurements

All measurements of passive drag were performed in a swimming flume (Speck Pump, 4 HP (400 G.P.M.), Jacksonville, FL) in which water was circulated via two jets at a velocity ranging from 1.2 to 3.0 m/s. A Flowmeter (FP6-201 Flow Probe Omega.com, Stamford, CT) was used to measure flow velocity to the nearest 0.1 m/s. Flow velocities of 2.0 and 2.5 m/s were chosen for the two test conditions to provide race-pace and faster-than-race-pace speeds. For each measurement of passive drag, the subjects submerged themselves in a prone position and grasped a nylon handle attached to a tethering cable (Figure 3). The subject was maintained in a horizontal position approximately 40 cm below the water surface in the flume's flow. To achieve this

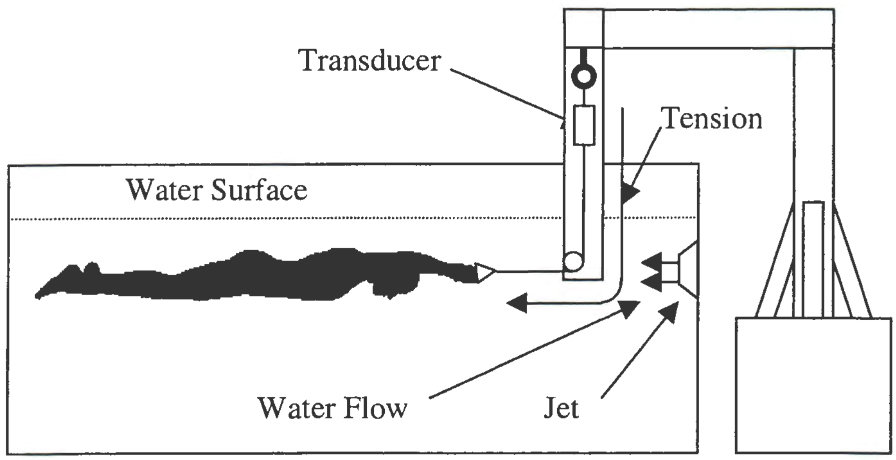

Figure 3. Apparatus and swim flume used to test passive drag

position, it was necessary for some subjects to use a floatation device between their legs to prevent them from sinking. Drag force was measured as the tension developed in the cable holding the swimmer in a stationary position. This tension was measured using a SM-250 strain-gauge force transducer (Interface Inc., Scottsdale, AZ) calibrated to the nearest 0.25 N. Transducer output was sampled at a frequency of 50 Hz and low-pass filtered at 1 Hz using an MP-100 A/D board and Acqknowledge 3.6 software (Biopac. Inc., Goleta, CA). Average drag force was computed for the final 8 seconds of a 10-second trial.

Buoyancy Measurement

The buoyant force was measured using a device that allowed the measurement to be made with the swimmer in a horizontal prone body position similar to one used when the swimmers glided under water (Figure 4) (6). The body was supported using a cranial tether attached to the trunk around the chest and a caudal tether attached to the ankle around the lateral malleolus. The position between the two tethers was set at 1.2 m. This

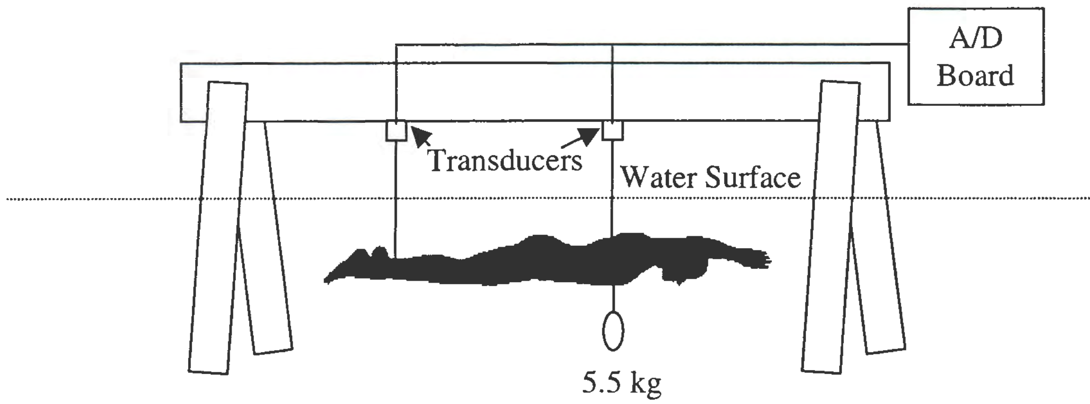

Figure 4. Apparatus used to measure the buoyant force

caused the placement of the cranial tether to vary slightly depending on the height of the subject. For all trials, each subject was at full inhalation and was completely submerged to a position 30 cm below the surface of the water in a prone position. Mass was added to the cranial tether (5.5 kg) to maintain the swimmer in a horizontal position underwater. Supporting force measurements were measured using SM-250 strain-gauge force transducers (Interface Inc., Scottsdale, AZ) calibrated to the nearest 0.25 N. Transducer output was sampled at a frequency of 25 Hz and low pass filtered at 1 Hz. The measured resultant cranial and caudal supporting forces were adjusted by subtracting the forces measured by the force transducers when supporting only the tethers and the stabilizing mass. Buoyant force was then calculated as

$$B = W - S_{cranial} - S_{caudal} \tag{4}$$

where W was the subject's weight, $S_{cranial}$ and S_{caudal} were the adjusted supporting tether forces, respectively.

Statistical Analysis

Absolute data for mean swim velocity, post-swim blood lactic acid concentration, oxygen uptake, ratings of perceived exertion, stroke length, stroke rate and breakout distance were analyzed using separate 3×2 (intensity $\times$ suit) repeated measures ANOVA's. The standardized post-swim oxygen uptake, blood lactate concentration, and ratings of perceived exertion were then analyzed using separate 3×2 (intensity $\times$ suit) repeated measures ANOVA. A $3 \times 2 \times 2$ (trial $\times$ suit $\times$ speed) repeated measures ANOVA was used to analyze the passive drag measurements. Buoyancy was evaluated using one-way repeated measures ANOVA.

Results

Subject's ratings of perceived exertion were similar between suit conditions at each of the three effort levels ($p = 0.43$) but mean velocities for the 183-m freestyle swims were faster ($p < 0.01$) when wearing the body suit than the brief-style suit (Table 1). Nine out of ten swimmers swam 1% to 3% faster when wearing the body suit regardless of whether they used it in the first or second testing session. Mean stroke length was 3% to 5% longer in the body suit trials than in the brief-style suit trials ($p = 0.03$) (Table 1), but there was no difference in stroke rate ($p = 0.64$) (Table 1). Although breakout distance tended to be longer when wearing the body suit than the brief-style suit, the difference was not significant ($p = 0.17$) (Table 1). Commensurate with the faster velocities chosen by the swimmers while wearing the body suit, the post-swim blood lactate concentration was significantly elevated ($p = 0.02$) (Table 1). Post-swim oxygen uptake was elevated in the body suit trial, but this difference was not significant ($p = 0.23$) (Table 1).

Table 1. Post-swim physiologic variables and stroke characteristics [Mean ± SE; (effect size for between suit comparisons)].

	Brief-Style Suit			Body Suit		
Variable	Swim 1	Swim 2	Swim 3	Swim 1	Swim 2	Swim 3
Velocity (m/s)	1.42 ± 0.02* (0.33)	1.52 ± 0.03* (0.25)	1.60 ± 0.03* (0.44)	1.45 ± 0.02	1.54 ± 0.03	1.64 ± 0.03
BLa (mmol/l)	5.9 ± 0.1* (3.00)	7.3 ± 0.1* (4.00)	9.8 ± 0.3* (0.63)	6.8 ± 0.2	8.1 ± 0.3	10.3 ± 0.5
VO_2 (l/min)	3.28 ± 0.10 (0.03)	3.73 ± 0.11* (0.74)	4.08 ± 0.11* (0.53)	3.29 ± 0.12	3.98 ± 0.14	4.26 ± 0.16
RPE	11 ± 1 (0.50)	15 ± 0 (0.00)	18 ± 0 (0.00)	12 ± 1	15 ± 0	18 ± 0
SL (m/stroke)	2.56 ± 0.06* (0.74)	2.47 ± 0.05* (0.69)	2.35 ± 0.03* (0.60)	2.70 ± 0.08	2.58 ± 0.08	2.41 ± 0.06
SR (strokes/min)	29.9 ± 1.0 (0.94)	33.6 ± 0.9 (-0.41)	37.3 ± 0.7 (0.04)	32.8 ± 0.9	32.4 ± 0.9	37.4 ± 1.0
BD (m)	5.96 ± 0.26 (0.29)	5.80 ± 0.21 (0.17)	5.57 ± 0.18 (0.23)	6.20 ± 0.19	5.91 ± 0.15	5.70 ± 0.14

* = significant at the $p < 0.05$ level between the brief-style suit and the corresponding body suit swims
BLa = blood lactate concentration
VO_2 = oxygen uptake
RPE = rating of perceived exertion
SL = stroke length
SR = stroke rate
BD = breakout distance

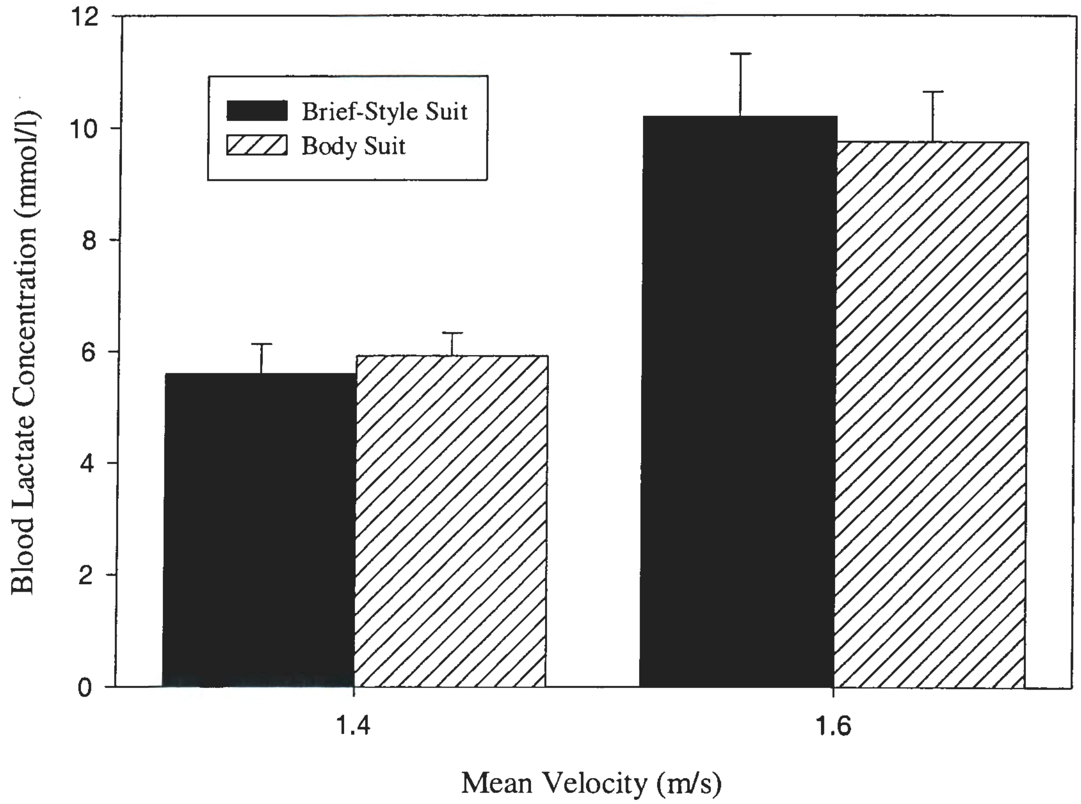

Figure 5. Group mean (± SE) post-swim blood lactate concentrations at submaximal swimming velocities of 1.4 and 1.6 m/s. There was no significant difference in blood lactate response between suits ($p>0.05$).

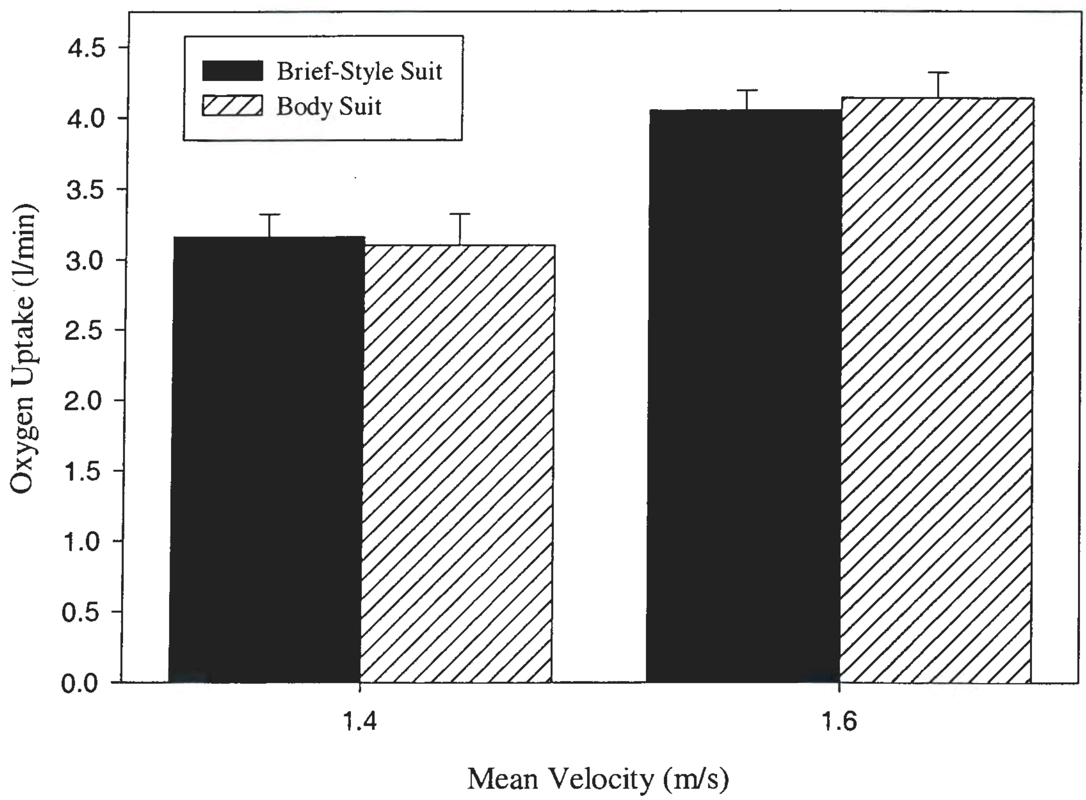

Figure 6. Group mean (± SE) post-swim oxygen uptake values at submaximal swimming velocities of 1.4 and 1.6 m/s. There was no significant difference in the oxygen uptake response between the suits ($p>0.05$).

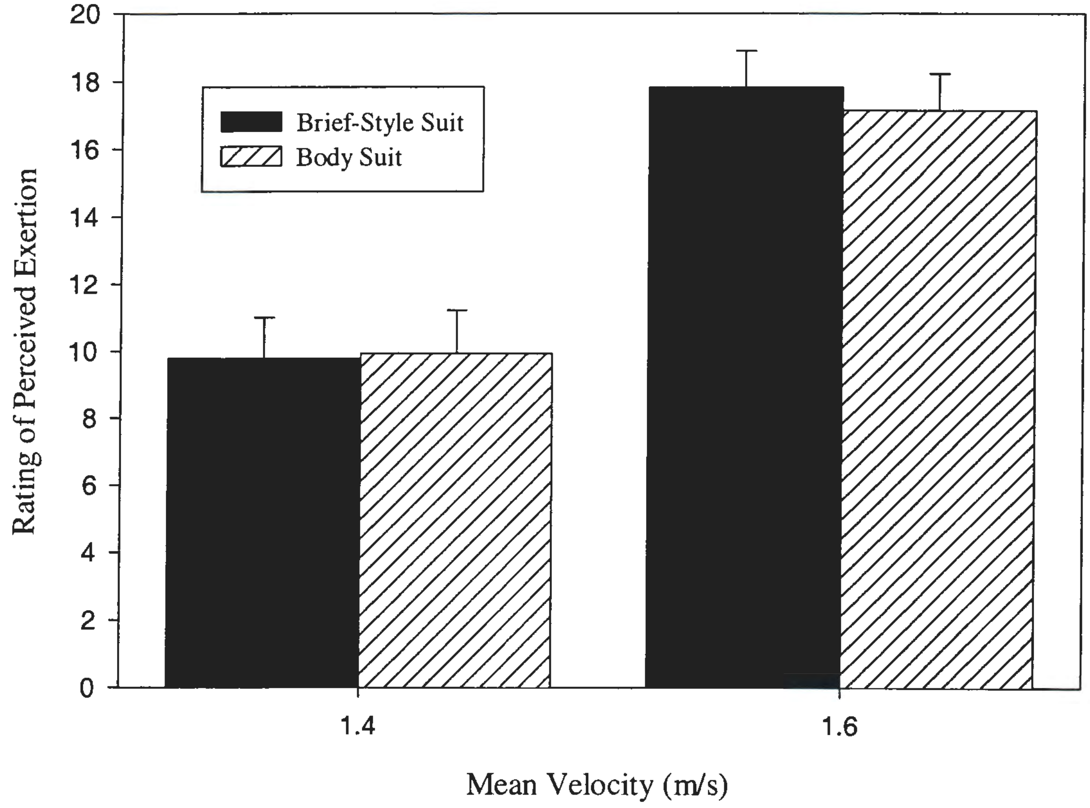

Figure 7. Group mean (± SE) ratings of perceived exertion at submaximal swimming velocities of 1.4 and 1.6 m/s. There was no significant difference in ratings of perceived exertion between the suits ($p>0.05$).

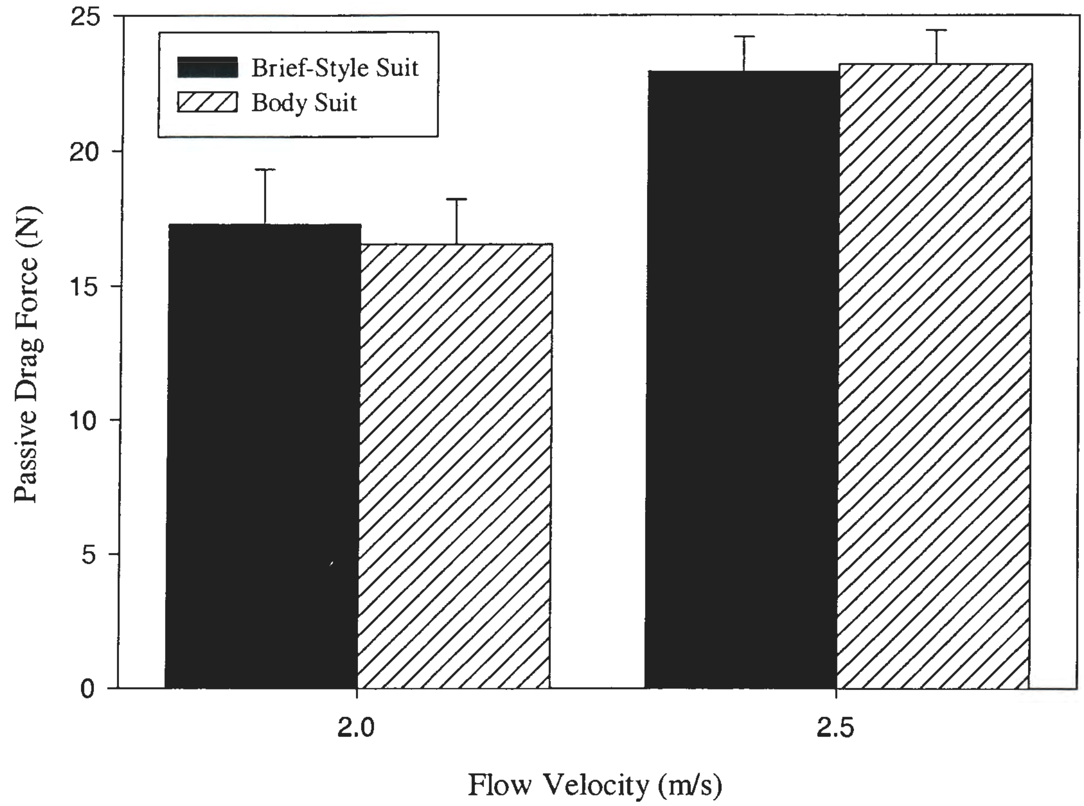

Figure 8. Group mean (± SE) passive drag forces at water flow velocities of 2.0 and 2.5 m/s. There was no significant difference in passive drag force between the suits ($p>0.05$).

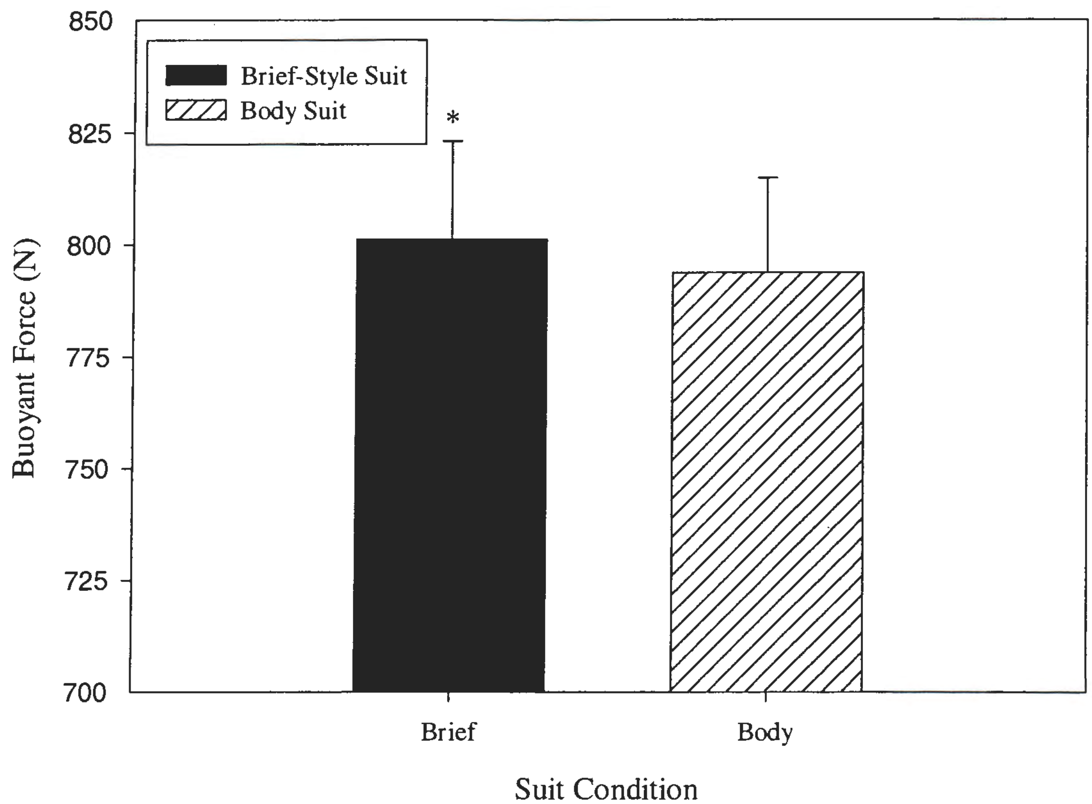

Figure 9. Group mean (± SE) buoyant forces for the brief-style and body suits. Swimmers were significantly more buoyant while wearing the brief-style suit than the body suit ($p<0.05$).

Because the swimmers did not duplicate their swim velocities in the two swim trials, physiological variables were predicted using linear regression at given submaximal speeds of 1.4 and 1.6 m/s for each swim under each condition. At mean velocities of 1.4 and 1.6 m/s, post-swim blood lactate concentration ($p = 0.91$), post-swim oxygen uptake ($p = 0.91$), and rating of perceived exertion ($p = 0.70$) were not different between suit conditions (Figures 5, 6, and 7 respectively).

Passive drag measured in the flume was not reduced ($p = 0.70$) when wearing the body suit compared to the brief-style suit (Figure 8). The drag measurements were reliable since there was no difference in drag measurements between the three replicated trials ($p = 0.98$) at each speed. Unexpectedly, swimmers were significantly more buoyant while wearing the brief-style suit than the body suit ($p < 0.01$) (Figure 9).

Discussion

The purpose of this study was to assess the effect of wearing a Fastskin™ swimsuit compared to a traditional brief-style racing suit while examining physiological variables, such as oxygen uptake and blood lactic acid concentration, and biomechanical variables, including passive drag, buoyancy and stroke characteristics. It was hypothesized that the body suit would not alter the physiological or biomechanical variables associated to swim performance.

The major finding of this study was that use of the body suit did not affect the metabolic cost of swimming at given submaximal speeds. The 1.4 and 1.6 m/s standardized velocities were selected to represent a slower and a faster swim velocity. They were also selected because these speeds were close to falling within the range of speeds chosen by the swimmers. The standardized physiological results revealed that wearing a body suit did not reduce the physiologic cost of swimming compared to the brief-style suit at the speeds of 1.4 and 1.6 m/s. The standardized oxygen uptake and blood lactate values of this study were not significantly different while wearing the body suit compared to the brief, but the oxygen uptake results were 2% lower and 2% higher and the blood lactate results were 6% higher and 4% lower at 1.4 and 1.6 m/s respectively. This is contrary to the finding of the Sharp et al. (9) shaving study involving four 183-m freestyle swims. At standardized speeds of 1.08 and 1.30 m/s the researchers found that blood lactate concentrations were reduced 28% and 23% post-shave respectively for the two speeds (9). In a later shaving study, Sharp and Costill (8) controlled for speed by using pacer lights and found that VO_2 and blood lactate accumulation post-364-m breaststroke swim were significantly lower by 9% and 20% from pre- to post-shave respectively (8). A study involving a torso swimsuit made of similar material to the body suit used in this study found a 4% decrease in VO_2 and a 16% decrease in blood lactate accumulation after swimming a 366-m freestyle swim at a fixed velocity (10). Both shaving studies and the torso suit study suggest that a reduction in active drag is responsible for the reduced metabolic cost. The lack of effect of the body suit on physiological results in this study suggests that these body suits had no effect on active drag.

Swimmers swam at a faster average velocity when wearing the body suit for the three swims. The data obtained during and after the third swim were most pertinent because they provided the closest comparison to a race-pace speed. The higher average speed when wearing the body suit was due to a longer stroke length and unchanged stroke rate. However, these positive changes in performance were not accompanied by beneficial changes in physiological variables. Concomitant with the faster speeds, there was a significant 4% to 6% increase in post-swim VO_2 and a significant 5% to 15% increase in post-swim blood lactate concentration. If the body suit had allowed the faster swimming speeds by reducing drag, VO_2 and blood lactate concentration responses would be lower or unchanged. This implied the swimmers chose to swim at a harder intensity during the body suit trials, despite the ratings of perceived exertion not being significantly different between the two suits. This suggested the swimmers felt like they were exerting the same effort in both conditions, but in reality were swimming at a higher physiological intensity with the body suit.

The faster average speed while wearing the body suit was due to a longer stroke length and unchanged stroke rate. This is similar to the findings of the shaving studies where the longer stroke length led to an improved swim speed that the authors speculated was due to a decrease in active drag (8,9). However, unless comparisons are made at the same velocities such comparisons are tenuous. Although the subjects swam faster with a longer stroke length while wearing the body suit it was done so at an elevated metabolic cost. A possible explanation for the results could be a psychological advantage of wearing a body suit. It is proposed that subjects expected to swim faster with the body suit and thus performed accordingly.

Although the body suits had no effect on physiological responses to submaximal swimming, the swimmers did perceive improved turn performance, particularly during the glide phase after push-off. Our measure of breakout distance was approaching significance, but was not affected significantly by the body suit. No difference in breakout distance is further supported by the low calculated effect sizes. There was also no effect of the body suit on the passive surface drag measurement used in this study. Since the body position of the glide phase after wall push-off and the body position of our passive drag measurement were similar, neither the decrease in passive surface drag nor the improved turn performance can explain the faster swim time. Again this suggests that both faster chosen speeds and perception of turn performance were more likely a result of subjects' expectations than the effect of swimsuit design.

Previous research has found that the use of neoprene wet suits can manipulate the buoyancy characteristics which in turn can lead to improved performance through decreased drag and decreased metabolic cost (3,7,10,11,12). Results of this study indicate that the subjects were actually more buoyant while wearing the brief-style suit than the body suit. This probably occurred because the body suit restricted the ability of the swimmer to take as deep an inhalation, which would make the body more buoyant, as the one taken while wearing the brief-style suit. The change in buoyancy and the subsequent decrease in total active drag found while wearing a wet suit is what differentiates all wet suit studies to date from this study because there is no increased buoyancy or decreased passive drag found with our body suits.

Even with the lack of physiological and biomechanical support found in this study, critics and the manufacturer may argue that individuals will react differently to these body suits. At this time it is important to mention that nine of the ten swimmers were non-responders to the suit. A responder was defined as a swimmer whose post-swim blood lactate concentration and post-swim oxygen uptake were decreased and whose stroke length increased while wearing the body suit. Only one individual displayed characteristics to qualify him as a responder and his results were similar to both shaving and wet suit studies. It appears that if the body suit enhances performance as claimed by the manufacturer it must be through some other mechanism than those tested in this study. A logical explanation would be the psychological benefits to wearing the body suit. Another explanation could be that the suit does not work with certain stroke mechanics and body types, which would imply that only certain swimmers would benefit from the use of a body suit.

No evidence was found to indicate physiological or biomechanical benefits of wearing a body suit as compared to a brief-style suit. The possible psychological effects to improve performance cannot be discounted, however, and may account for the observation of a longer stroke length and faster chosen speeds on the three 183-m freestyle swims in this study. Therefore, it is concluded that combined effect of increased body surface area covered and design of the suit material has no measurable effect on submaximal responses to swimming. Because no attempt was made to evaluate effects on maximal performance this question remains for future investigations. Future research may also wish to assess the psychological states of the swimmers prior to and during competition, as well as explore the velocity decay data of wall push-off since that could not be examined with the breakout distance of this study. A final area to be examined would be the effects of the different styles of body suits and their effect on the other swim strokes.

Acknowledgements

We would like to thank Stuart Isaac for donation of the Fastskin™ swimsuits. We would also like to thank Ron Leibold for assistance in building the passive drag and buoyancy equipment. Finally we would like to thank Josh Thomas and Evan deSzoeke, for their assistance in data collection and Khaled Kamel for his help in data collection and analysis.

References

1. Borg, G. Perceived exertion: A note on "history" and methods. *Med. Sci. Sports Exerc.* 5:90-93, 1973.
2. Capelli, C., Zamparo, P., Cigalotto, A., et al. Bioenergentics and biomechanics of front crawl swimming. *Journal of Applied Physiology.* 78:674-679, 1995.
3. Chatard, J.-C., Senegas, X., Selles, M., Dreanot, P., and Geyssant, A. Wet suit effect: A comparison between competitive swimmers and triathletes. *Med. Sci. Sports Exerc.* 27:580-586, 1995.
4. Costill, D. L., Kovaleski, D., Porter, D., Kirwan, J., Fielding, R., and King, D. Energy expenditure during front crawl swimming: Predicting success in middle distance events. *Int. J. Sports Med.* 6:266-270, 1985.
5. Hinrichs, R. N. and Morrison, B. J. New "long john" swimming suits worn at the 2000 olympics. *American College of Sports Medicine Fit Society Page.* Oct.-Dec.:1-7, 2000.
6. McLean, S. P. and Hinrichs, R. N. The influence of arm position and lung volume on the center of buoyancy of competitive swimmers. *Res. Q. Exerc. Sport.* 71:182-189, 2000.
7. Parsons, L. and Day, S. J. Do wet suits affect swimming speed? *Br. J. Sports Med.* 20:129-131, 1986.
8. Sharp, R. L. and Costill, D. L. Influence of body hair removal on physiological responses during breaststroke swimming. *Med. Sci. Sports Exerc.* 21:576-580, 1989.

9. Sharp, R. L., Hackney, A. C., Cain, S. M., and Ness, R. J. The effect of shaving body hair on the physiological cost of freestyle swimming. *J. Swimming Res.* 4:9-13, 1988.

10. Starling, R. D., Costill, D. L., Trappe, T. A., Jozsi, A. C., Trappe, S. W., and Goodpaster, B. H. Effect of swimming suit design on the energy demands of swimming. *Med. Sci. Sports Exerc.* 27:1086-1089, 1995.

11. Toussaint, H. M., Bruinink, L., Coster, R., De Looze, M., Van Rossem, B., Van Veenan, R., and De Groot, G. Effect of a triathlon wet suit on drag during swimming. *Med. Sci. Sports Exerc.* 21:325-328, 1989.

12. Trappe, T. A., Pease, D. L., Trappe, S. W., Troup, J. P., and Burke, E. R. Physiological responses to swimming while wearing a wet suit. *Int. J. Sports Med.* 17:111-114, 1996.

13. Zamparo, P., Capelli, C., Termin, B., Pendergast, D. R., and di Prampero, P. E. Effect of the underwater torque on the energy cost, drag, and efficiency of front crawl swimming. *European Journal of Applied Physiology.* 73:195-201, 1996.

CHAPTER III

CONCLUSIONS

In summary, the body suits did not decrease the physiologic cost of swimming. The body suits did not alter the biomechanic variables of passive drag and buoyancy in a positive manner. Despite all this, the swimmers swam at a faster absolute speed while wearing the body suits and this was accomplished with a significantly longer stroke length at a higher metabolic cost. This increase in speed would probably be best explained by a psychological effect of wearing the body suit.

APPENDIX

INFORMED CONSENT

Project Title: Effect of the Fastskin™ swimsuit on biomechanical variables and physiological cost of free-style swimming

Principal Investigators: Rick L. Sharp, Ph.D. 250 Forker Bldg. 294-8650

Scott McLean, Ph.D. 255 Forker Bldg. 294-8755

CONSENT FORM

The recent introduction of the Fastskin competitive swimsuit has been claimed to account for as much as 3% improvement in performance. It is claimed that the fabric used has less resistance to water flow than the human skin. The reduced water resistance therefore may improve performance by reducing the energy required to attain competitive speeds during races. Despite these claims, there is no published evidence to suggest the fabric behaves as claimed or whether the swimmers' energy cost is affected. It is the aim of this research to test these claims.

You will be asked to perform three 200-yard freestyle swims on two occasions: one day while wearing the traditional competitive swimsuit and while wearing the Fastskin suit on another day. The first 200 will be swum at a comfortable warm-up pace, the second at a moderate aerobic training pace (70% effort), and the last 200 at a 90% effort. Immediately after each 200your heart rate will be measured and a drop of blood will be taken from your fingertip and later analyzed for lactic acid concentration. We'll also have you breathe through a one-way breathing valve (similar to scuba) during this minute to measure oxygen uptake. Four minutes of rest will be allowed after each 200-yard swim.

On another day, we will measure your buoyancy in the two suits. This will require you to have an underwater weight measurement made with you wearing each suit. For this, you will submerge yourself in our underwater weighing tank, exhale completely and sit in a chair. You will need to remain motionless in this state for approximately 10 seconds. When the measurement is complete, we will signal you to rise to the surface. You may stop the measurements at any time. These measurements will be made with you wearing the Fastskin suit immediately after entering the water (from a dry state) and 20 minutes after being in the water and also with your traditional suit. Therefore, this section of the experiment will require three trials.

On a final day of testing we will measure the passive drag force acting on you when wearing each type of suit. This testing will be done in a swimming flume located in the Veterinary Training Hospital. The flume will circulate water past you at speeds varying from slow, warm-up pace, to a speed slightly faster than what you would be able to achieve when sprinting. For each measurement, you will maximally inhale, submerge yourself and grasp a handle attached to a tethering cable. You will assume a streamline position in the flow of the water at approximately 60 cm below the surface of the water. You will hold this position for 30 seconds while the force acting on the tethering cable is measured. Seven speeds will be used with the Fastskin and traditional suits. This means that you will perform 14 trials in this section of the experiment.

At any time during the study you may withdraw your consent to participate without prejudice towards you. Such withdrawal may be for any reason you choose. Constant monitoring of all experiments will be performed by knowledgeable and CPR training individuals in an attempt to prevent any complications. Emergency first aid supplies and equipment will be immediately available.

Emergency treatment of any injuries that may occur as a direct result or participation in this research will be treated at the Iowa State University Student Health Services, Student Services Building, and/or referred to Mary Greeley Medical Center or another physician. Compensation for treatment of any injuries that may occur as a direct result of participation in this research may or may not be paid by Iowa State University depending on the Iowa Tort Claims Act. Claims for compensation will be handles by the Iowa State University Vice President for Business and Finance.

Your questions on any aspect of this research project are welcomed. At the conclusion of the study you will be informed of the results of the study and the conclusions drawn. Your results will be kept absolutely confidential and should your data be used in publication of the results, your name or any identifying characteristics will not be reported.

* * * *

Name:______________________________ Witness:________________________

Date:_______________

REFERENCES

1. Arabas, C., Mayhew, J. L., Hudgins, P. M., and Bond, G. H. Relationships among work rates, heart rates, and blood lactate levels in female swimmers. *J. Sports Med.* 27:291-295, 1987.

2. Capelli, C., Zamparo, P., Cigalotto, A., et al. Bioenergentics and biomechanics of front crawl swimming. *J. Appl. Physiol.* 78:674-679, 1995.

3. Chatard, J. C., Collomp, C., Maglischo, E., and Maglischo, C. Swimming skill and stroking characteristics of front crawl swimmers. *Int. J. Sports Med.* 11:156-161, 1990.

4. Chatard, J. C., Lavoie, J. M., Bourgoin, B., and Lacour, J. R. The contribution of passive drag as a determinant of swimming performance. *Int. J. Sports Med.* 11:367-372, 1990.

5. Chatard, J. C., Lavoie, J. M., and Lacour, J. R. Analysis of determinants of swimming economy in front crawl. *Eur. J. Appl. Physiol.* 61:88-92, 1990.

6. Chatard, J.-C., Senegas, X., Selles, M., Dreanot, P., and Geyssant, A. Wet suit effect: A comparison between competitive swimmers and triathletes. *Med. Sci. Sports Exerc.* 27:580-586, 1995.

7. Costill, D. L., Kovaleski, D., Porter, D., Kirwan, J., Fielding, R., and King, D. Energy expenditure during front crawl swimming: Predicting success in middle distance events. *Int. J. Sports Med.* 6:266-270, 1985.

8. Craig, A. B. and Pendergast, D. R. Relationship of stroke rate, distance per stroke, and velocity in competitive swimming. *Med. Sci. Sports Exerc.* 11:278-283, 1979.

9. Craig, A. B., Skehan, P. L., Powelczyk, J. A., and Boomer, W. L. Velocity, stroke rate, and distance per stroke during elite swimming competition. *Med. Sci. Sports Exerc.* 17:625-634, 1985.

10. Di Prampero, P. E., Pendergast, D. W., Wilson, D. W., and Rennie, D. W. Energetics of swimming in man. *J. Appl. Physiol.* 37:1-5, 1974

11. Holmer, I. Oxygen uptake during swimming in man. *J. Appl. Physiol.* 33:502-509, 1972.

12. Kame, V. D., Pendergast, D. R., and Termin, B. Physiologic responses to high intensity training in competitive university swimmers. *J. Swimming Res.* 6:5-8, 1990.

13. Klentrou, P. P. and Montpetit, R. R. Effect of stroke rate and body mass on VO_2 in crawl swimming. *J. Swimming Res.* 7:26-30, 1991.

14. Klentrou, P. P. and Montpetit, R. R. Physiologic and physical correlates of swimming performance. *J. Swimming Res.* 7:13-18, 1991.

15. Lyttle, A. D., Blanksby, B. A., Elliot, B. C., and Lloyd, D. G. The effect of depth and velocity on drag during the streamlined glide. *J. Swimming Res.* 13:15-22.

16. McLean, S. P and Hinrichs, R. N. Buoyancy, gender, and swimming performance. *J. Appl. Biomechanics.* 16:248-263, 2000.

17. McLean, S. P. and Hinrichs, R. N. The influence of arm position and lung volume on the center of buoyancy of competitive swimmers. *Res. Q. Exerc. Sport.* 71:182-189, 2000.

18. Parsons, L. and Day, S. J. Do wet suits affect swimming speed? *Br. J. Sports Med.* 20:129-131, 1986.

19. Ruschall, B., S., Holt, L.E., Sprigings, E. J., and Cappert, J. M. A re-evaluation of forces in swimming. *J. Swimming Res.* 10:6-30, 1994.

20. Sharp, R. L. and Costill, D. L. Influence of body hair removal on physiological responses during breaststroke swimming. *Med. Sci. Sports Exerc.* 21:576-580, 1989.

21. Sharp, R. L., Hackney, A. C., Cain, S. M., and Ness, R. J. The effect of shaving body hair on the physiological cost of freestyle swimming. *J. Swimming Res.* 4:9-13, 1988.

22. Starling, R. D., Costill, D. L., Trappe, T. A., Jozsi, A. C., Trappe, S. W., and Goodpaster, B. H. Effect of swimming suit design on the energy demands of swimming. *Med. Sci. Sports Exerc.* 27:1086-1089, 1995.

23. Toussaint, H. M., Beelen, A., Rodenburg, A., Sargeant, A. J., de Groot, G., Hollander, P., and van Ingen Schenau, G. J. Propelling efficiency of front-crawl swimming. *J. Appl. Physiol.* 65:2506-2512, 1988.

24. Toussaint, H. M., de Groot, G., Savelberg, H. H. C. M., Vervoorn, K., Hollander, A. P., and van Ingen Schenau, G. J. Active drag related to velocity in male and female swimmers. *J. Biomechanics.* 21:435-438, 1988.

25. Toussaint, H. M., Bruinink, L., Coster, R., De Looze, M., Van Rossem, B., Van Veenan, R., and De Groot, G. Effect of a triathlon wet suit on drag during swimming. *Med. Sci. Sports Exerc.* 21:325-328, 1989.

26. Trappe, T. A., Pease, D. L., Trappe, S. W., Troup, J. P., and Burke, E. R. Physiological responses to swimming while wearing a wet suit. *Int. J. Sports Med.* 17:111-114, 1996.

27. Ueda, T. and Kurokawa, T. Relationships between perceived exertion and physiological variables during swimming. *Int. J. Sports Med.* 16:385-389, 1995.

28. Zamparo, P., Capelli, C., Termin, B., Pendergast, D. R., and di Prampero, P. E. Effect of the underwater torque on the energy cost, drag, and efficiency of front crawl swimming. *Eur. J. Appl. Physiol.* 73:195-201, 1996.